

General Searches for New Physics



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Introduction



- Model-independent global search for new high- p_T physics in $p\bar{p}$ collisions at the Tevatron with CDF

Vista Examine population and kinematic features of high- p_T data

Bump Hunter Search for resonances in invariant mass combinations

Sleuth Look for excesses at high sum- p_T



- General search for new high- p_T physics in e^+p and e^-p collisions at HERA with H1

- Comparisons of event yields, sum- p_T , and invariant mass distributions to standard model expectations
- Largest deviations identified and probabilities evaluated

CDF Global Search Overview

- Capturing data

- Results use 2 fb^{-1}
- Events come in on inclusive high- p_T electron, muon, photon, and jet triggers

- Object identification

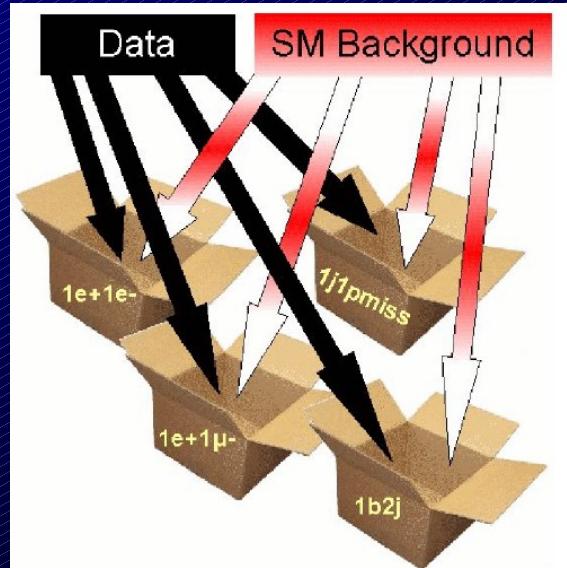
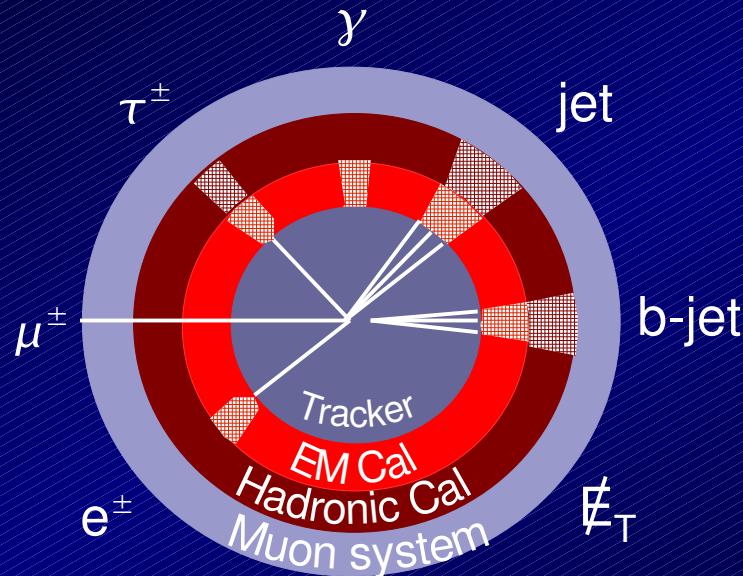
- $e^\pm, \mu^\pm, \tau^\pm, \gamma, j, b, \cancel{E}_T$
- $p_T > 17 \text{ GeV}/c$

- Selecting events

- Offline requirements such as $E_T(e) > 25 \text{ GeV}$, $p_T(\mu) > 25 \text{ GeV}/c$, or $E_T(\gamma) > 60 \text{ GeV}$, etc.

- Categorization

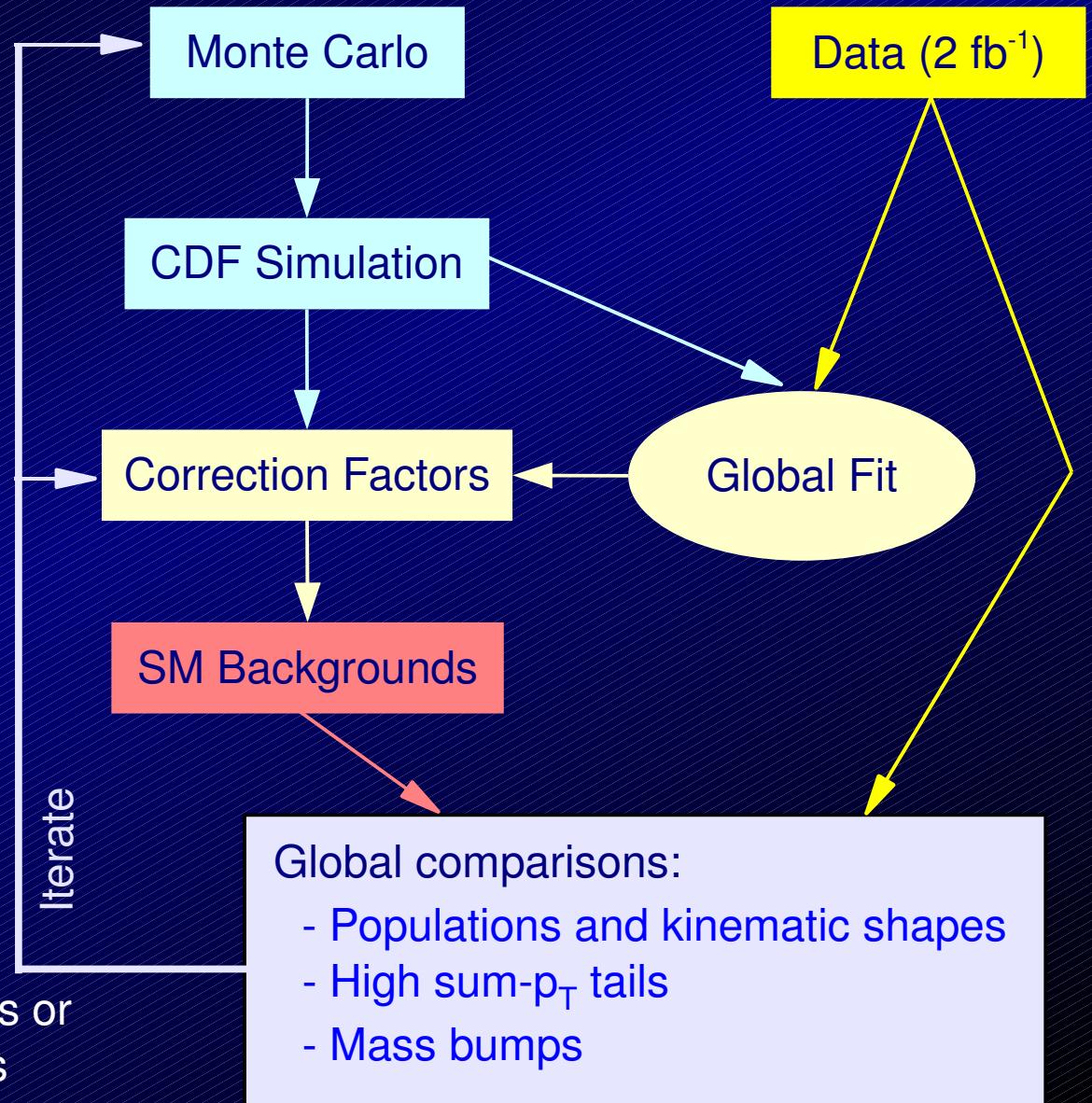
- ~4.3 million events partitioned into 399 exclusive final states
- New categories created as needed





CDF Global Search Strategy

- Use Monte Carlo event generators such as PYTHIA and MadEvent to mimic Standard Model
- Simulate CDF detector response using GEANT-based *CDFSim*
- Fit for 43 correction factors to improve SM prediction
 - Global fit to all final states, subject to external constraints
 - Leading order theory cross sections corrected
 - Object reconstruction efficiencies and mis-identification rates corrected
- Iterate until clear case for new physics or all discrepancies have known sources

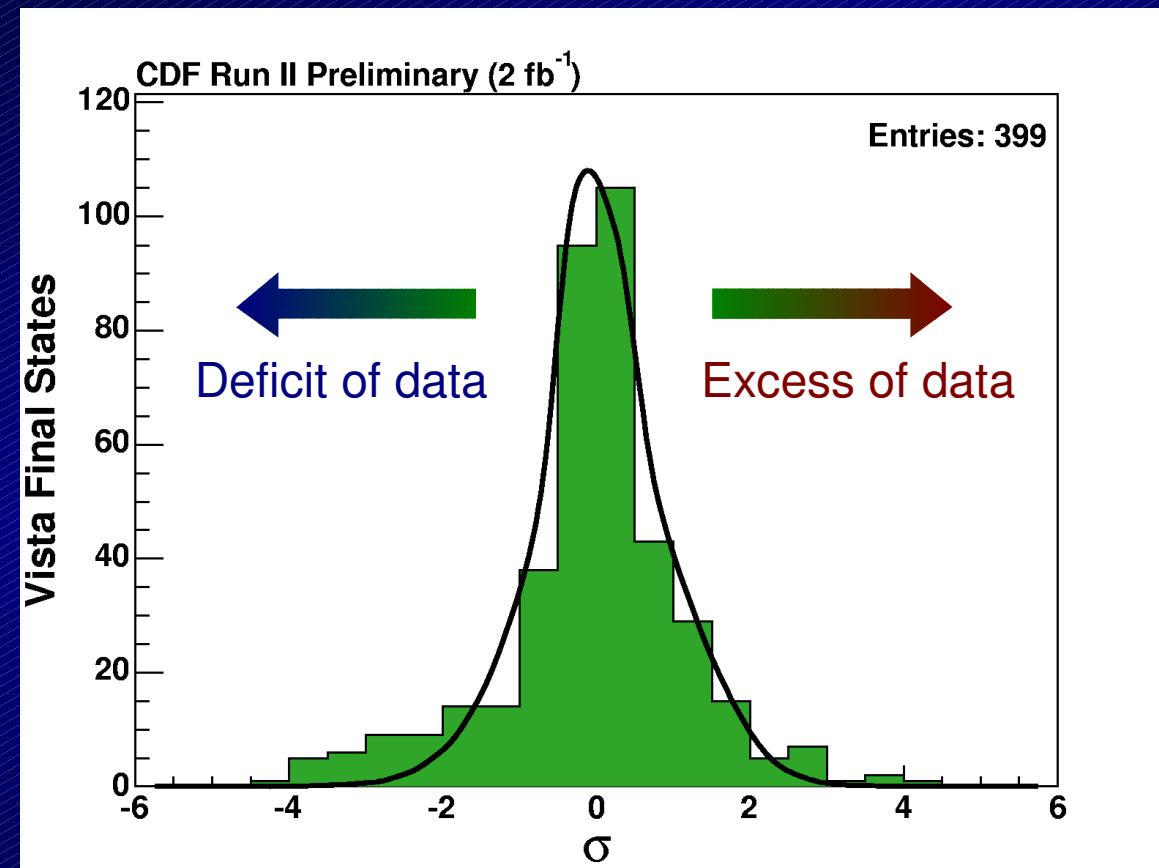


Population Results

- Summary of “Vista” final state population comparisons (data to SM bkg.)

| CDF Run II Preliminary (2.0 fb^{-1}) | | | |
|--|--------|---------------------|----------|
| Final State | Data | Background | σ |
| $be^\pm p$ | 690 | 817.7 ± 9.2 | -4.3 |
| $\gamma\tau^\pm$ | 1371 | 1217.6 ± 13.3 | +4.0 |
| $\mu^\pm\tau^\pm$ | 63 | 35.2 ± 2.8 | +3.7 |
| b2j p high- Σp_T | 255 | 327.2 ± 8.9 | -3.7 |
| 2j τ^\pm low- Σp_T | 574 | 670.3 ± 8.6 | -3.6 |
| 3j τ^\pm low- Σp_T | 148 | 199.8 ± 5.2 | -3.5 |
| $e^\pm p\tau^\pm$ | 36 | 17.2 ± 1.7 | +3.5 |
| 2j $\tau^\pm\tau^\mp$ | 33 | 62.1 ± 4.3 | -3.5 |
| $e^\pm j$ | 741710 | 764832 ± 6447.2 | -3.5 |
| j2 τ^\pm | 105 | 150.8 ± 6.3 | -3.4 |

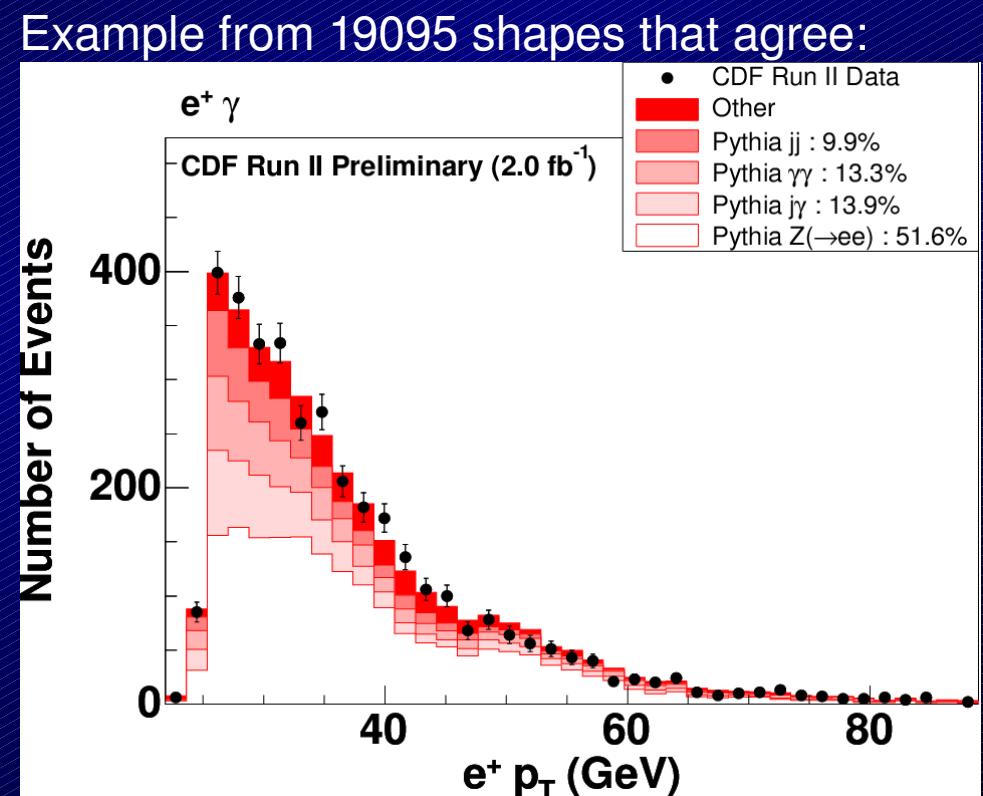
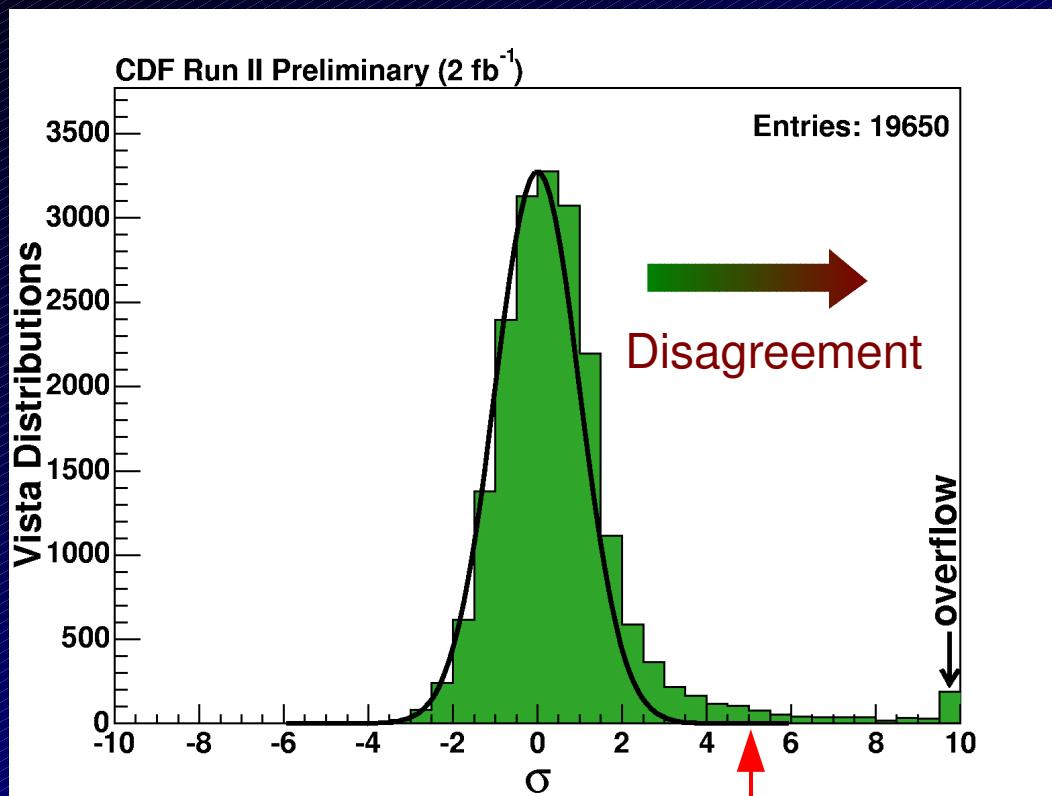
⋮ ⋮ ⋮ ⋮ ⋮
... plus 389 additional, less discrepant,
population comparisons



- No population shows a significant discrepancy after accounting for the trials factor (e.g. -4.3σ becomes -2.7σ)

Kinematic Distribution Results

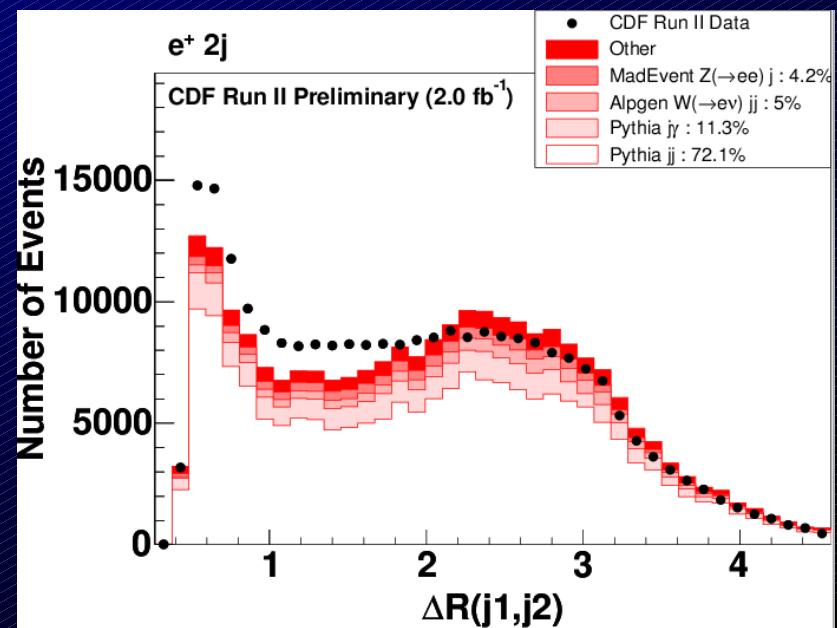
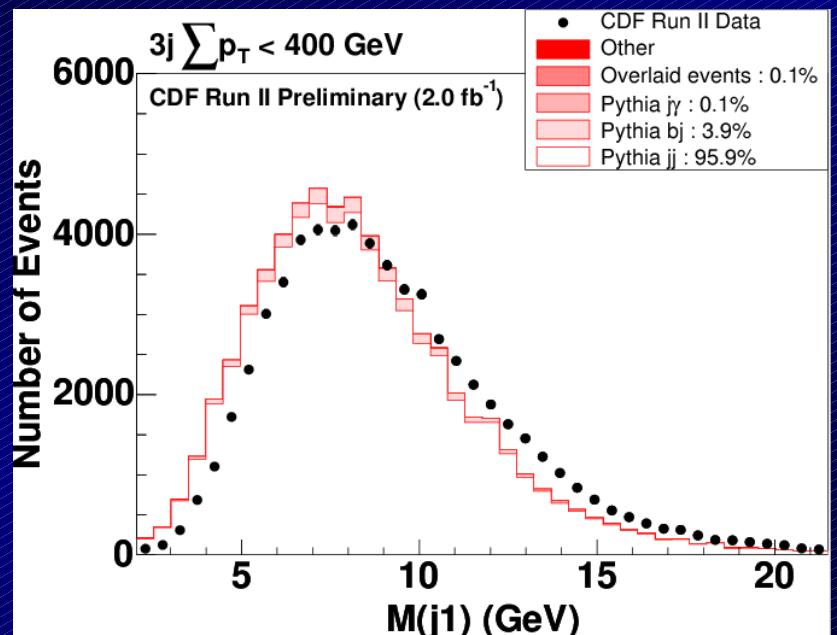
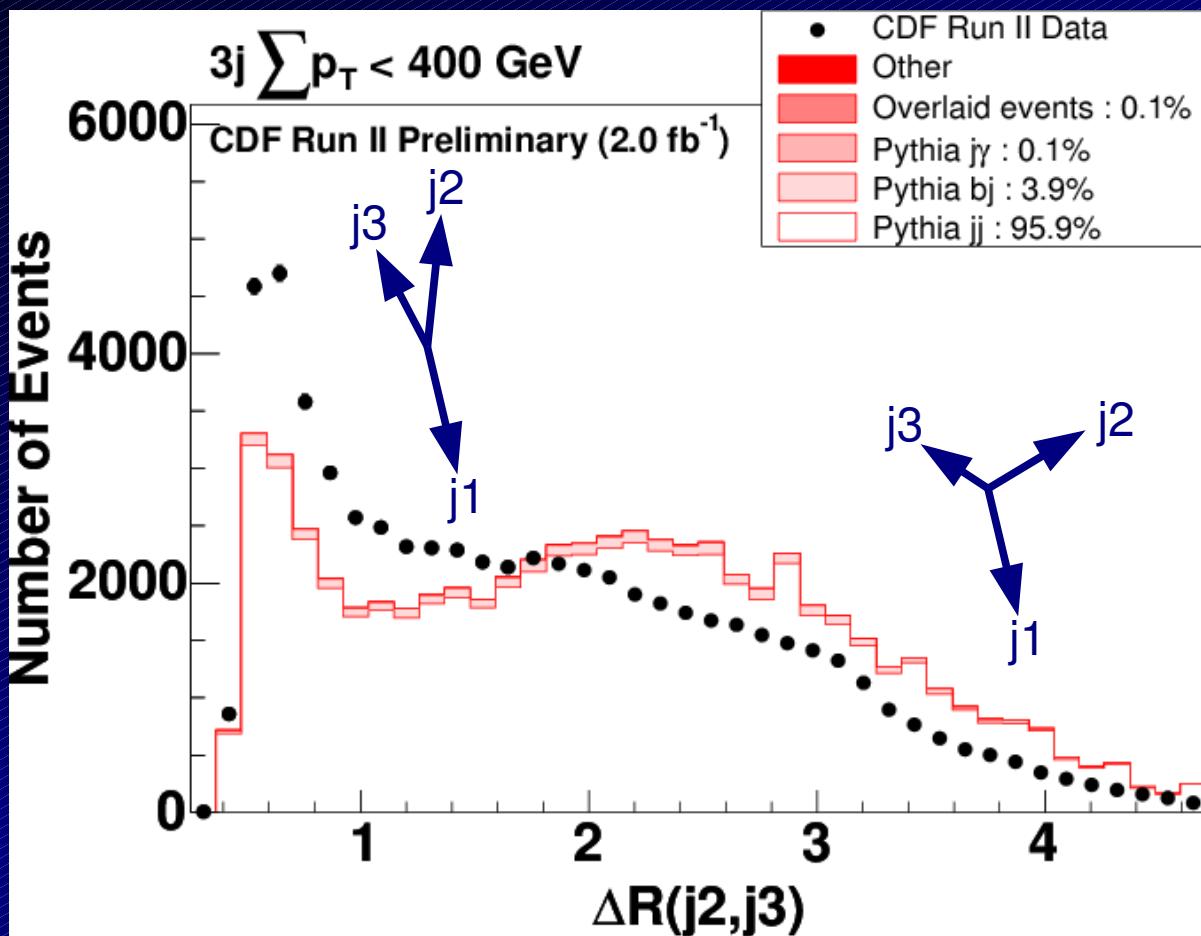
- Summary of “Vista” kinematic shape comparisons (data to SM bkg.)
- Automatically produces and examines 19650 kinematic distributions



- Inspect the 555 shapes with significant ($>5\sigma$) discrepancy more closely ...

Shape Discrepancies

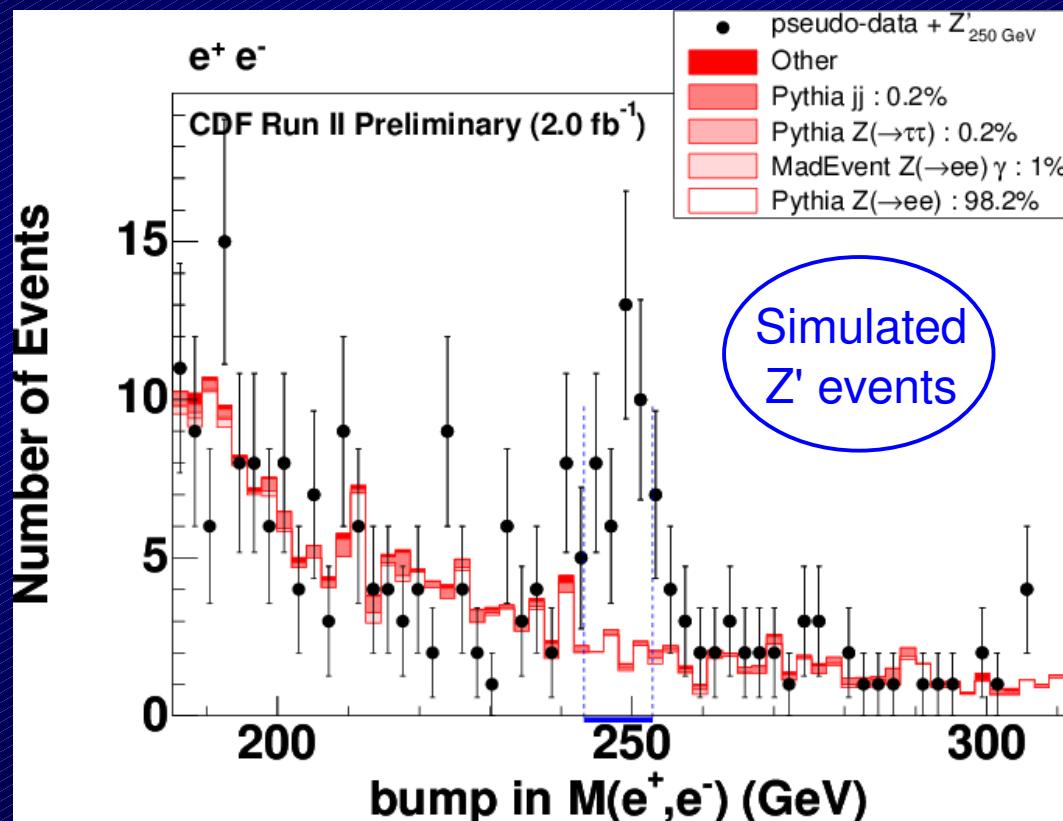
- Soft jet emission modeling problem
- No claims for new physics based on these



Bump Hunter

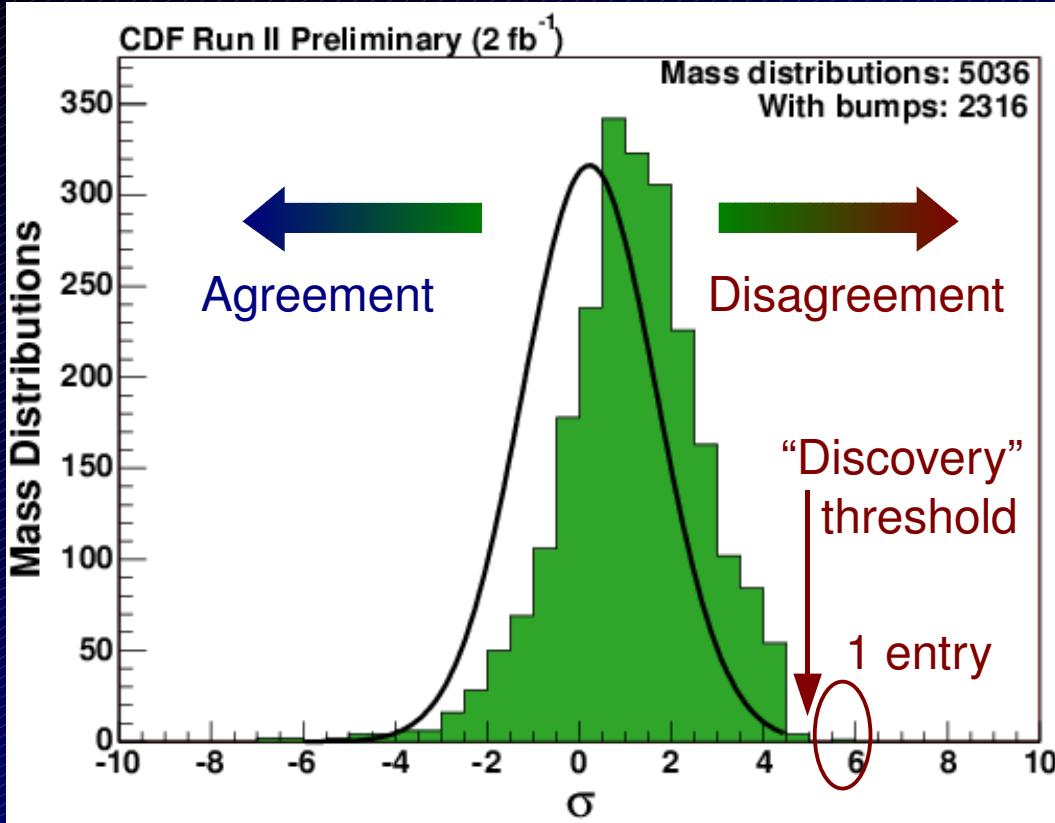
- Resonance might show up as bump in invariant mass
- Strategy:
 - Form all object mass combinations
 - Compare data to SM backgrounds
 - Use search window of $2\Delta M$
(ΔM = expected detector mass resolution)
 - Candidate bumps must have:
 - ≥ 5 data events
 - Side-bands in better agreement than center
 - Use pseudo-experiments to estimate significance of bumps

Example, using Z' events injected into a mix of pseudo-data based on SM backgrounds:





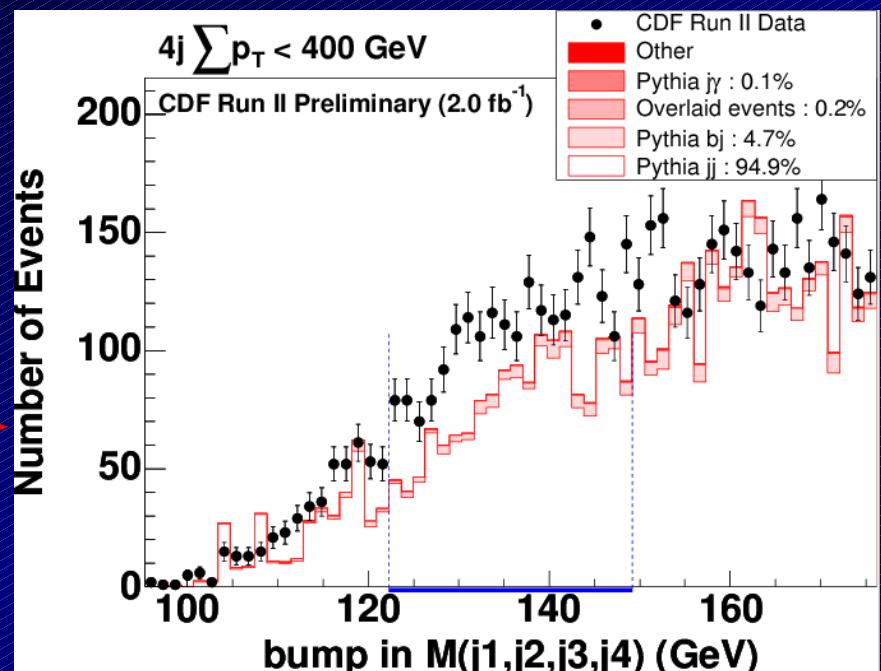
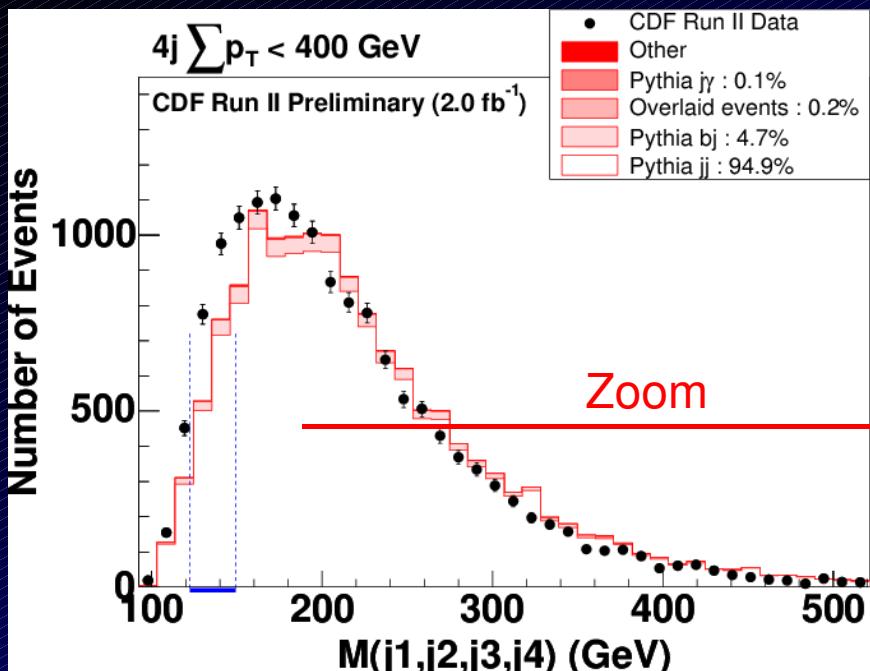
Bump Hunter Results



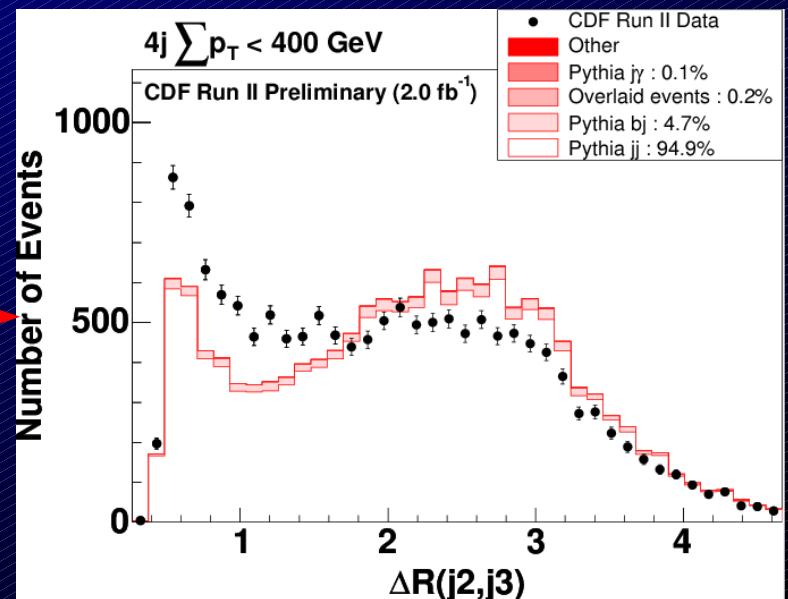
Probability for corresponding bump from pseudo-data to have larger significance than the one found in data

- 5036 mass distributions scanned
→ 2316 have qualifying bumps
- Shift caused by local deficiencies in the SM prediction
- “Discovery” threshold is 5σ , corresponding to 3σ after trials factor for 5036 distributions

Bump Hunter Results (II)

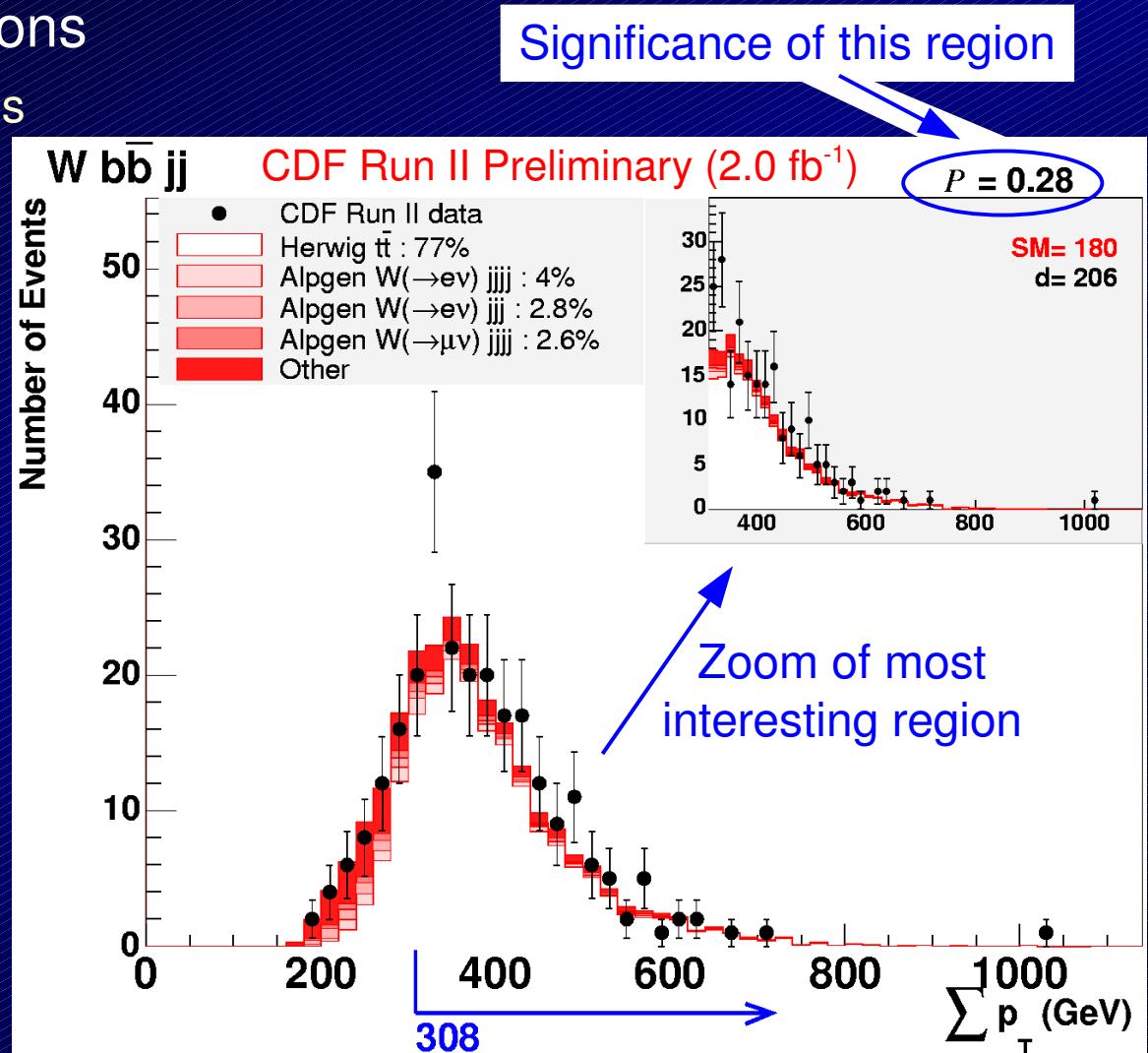


- The only significant bump
 - 4 jets and low $\sum p_T$
- But it's just due to the jet ΔR problem seen before
- No new physics found by the bump hunter in 2 fb^{-1}



High Σp_T

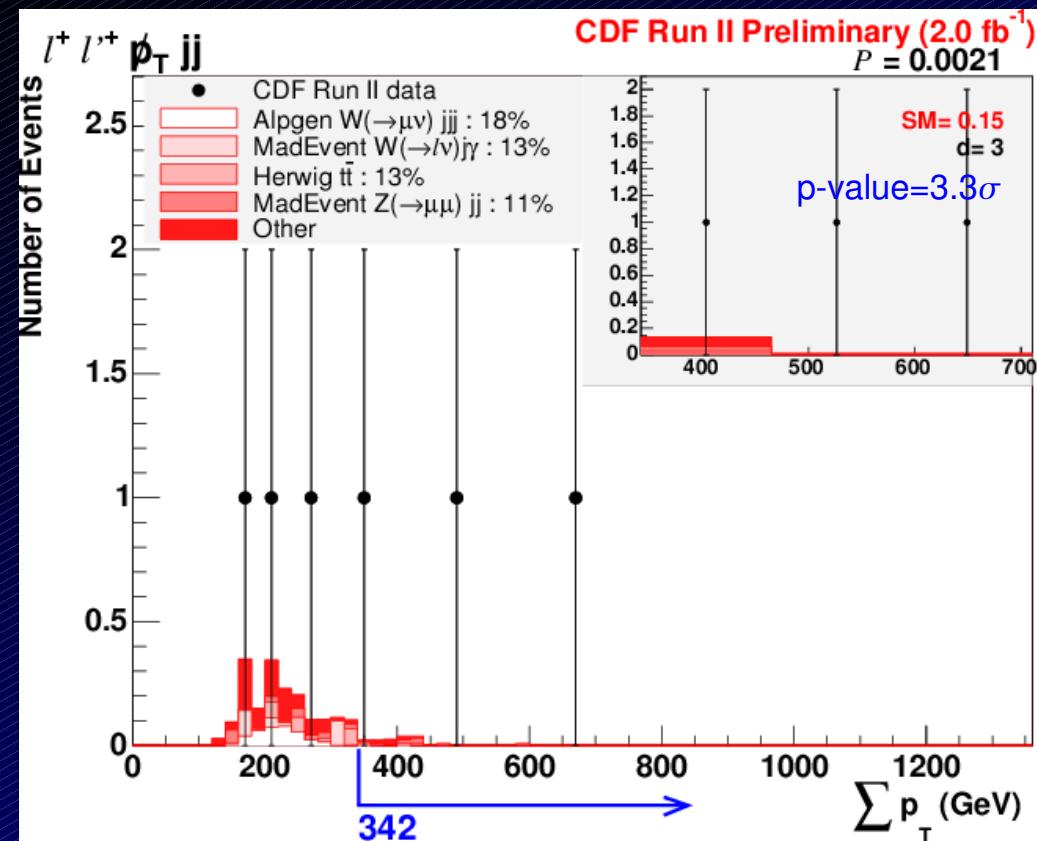
- “Sleuth” makes three assumptions
 - New physics will show up as excess
 - Excess will be at high Σp_T
 - Excess will be in one final state
- Search variable
 $\Sigma p_T \equiv \sum |\vec{p}_T| + |\vec{\text{uncl}}| + |\vec{\phi}_T|$
- For each final state
 - Scan the Σp_T distribution
 - Select the one-sided region with most significant excess of data
- Perform pseudo-experiments to evaluate significance



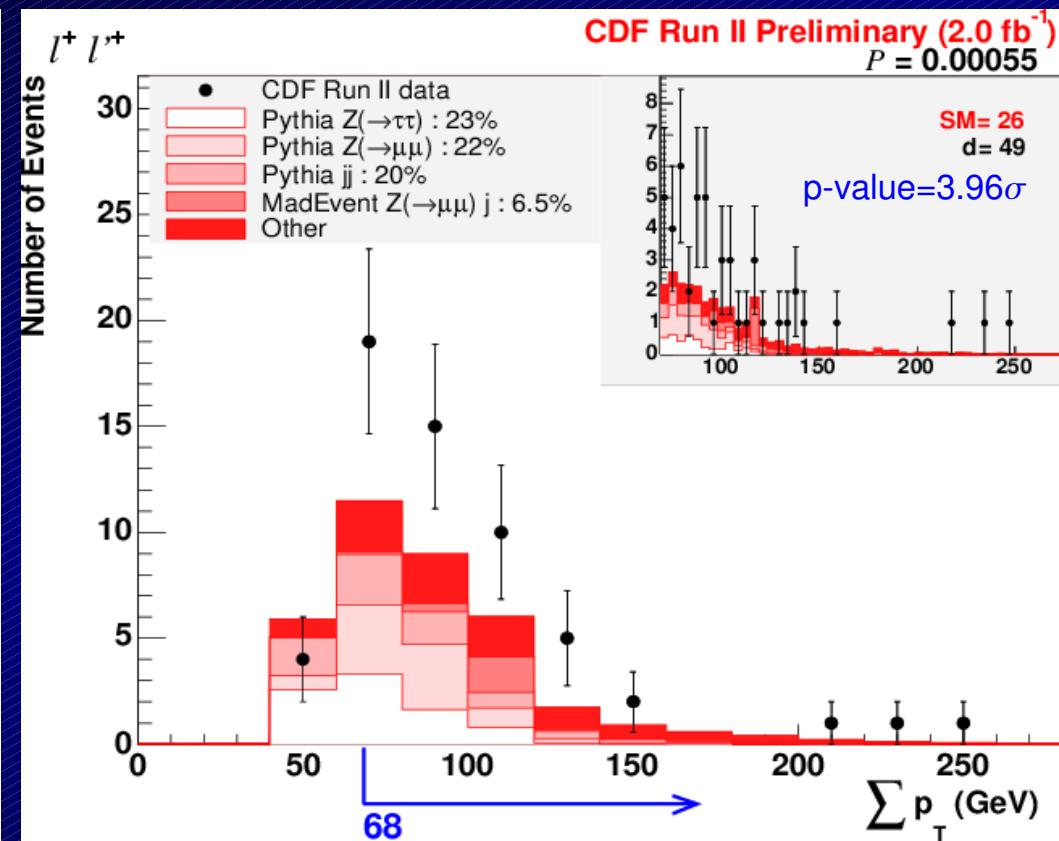


Sleuth Results

#2



#1



- Final state: $e^+ \mu^+ jj \not{p}_T$
- Significance of region:
 $P = 0.0021$ (2.86σ) before trials factor,
27% probable after trials factor

- Final state: $e^+ \mu^+$
- Significance of region:
 $P = 0.00055$ (3.26σ) before trials factor,
8.5% probable after trials factor



Sleuth Summary

- Top 5 most discrepant high Σp_T tails:

CDF Run II Preliminary (2.0 fb^{-1})

| Sleuth Final State | P |
|---------------------------------|---------|
| $e^+ \mu^+$ | 0.00055 |
| $e^+ \mu^+ jj \not{p}_T$ | 0.0021 |
| $e^+ \mu^+ \not{p}_T$ | 0.0042 |
| $\ell^+ \ell^- \ell' \not{p}_T$ | 0.0047 |
| $\ell^+ \tau^+ \not{p}_T$ | 0.0065 |

- Last step is to calculate what fraction of CDF-like experiments would find an excess at least as large as the top Sleuth final state:

Answer = ~8%

- Therefore, no claim for discovery of new physics using Sleuth on 2 fb^{-1}
(but there certainly can still be new physics in the CDF data)

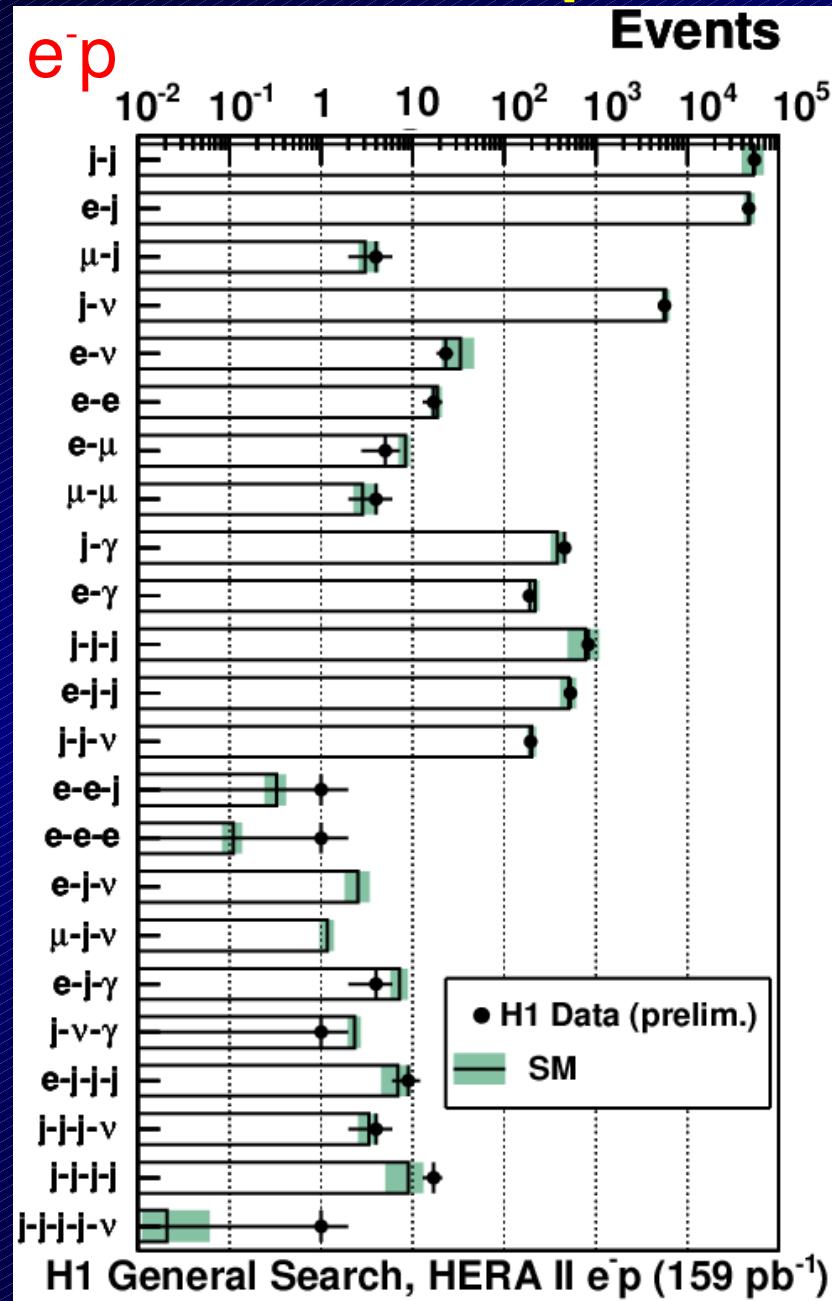
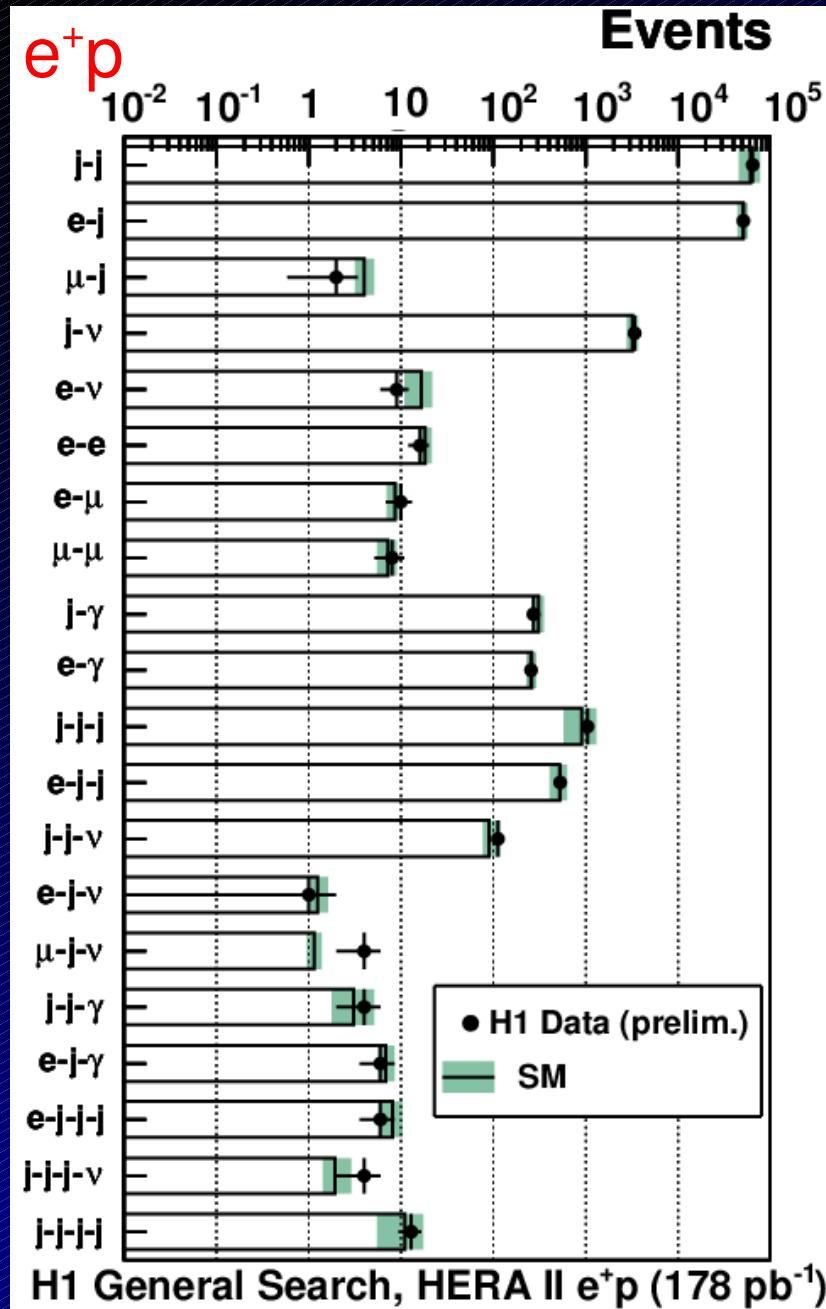


H1 General Search Strategy

- Complete HERA II sample (2003-2007)
 - 178 pb^{-1} e^+p and 159 pb^{-1} e^-p
- Object identification
 - Isolated $e^\pm, \mu^\pm, \gamma, j, \nu$
 - $p_T > 20 \text{ GeV}/c$
 - $10^\circ < \theta < 140^\circ$
- Event classification
 - By number and type of object
 - Takes exclusive final states with ≥ 2 objects
 - 23 final states are populated
- Simulations for all contributing SM processes
 - Photoproduction, deep-inelastic scattering, QED Compton scattering, electroweak, W production, QCD
- Compare event yields, Σp_T , and invariant mass distributions to SM
- Identify largest deviations and evaluate probabilities



H1 Event Yield Comparison

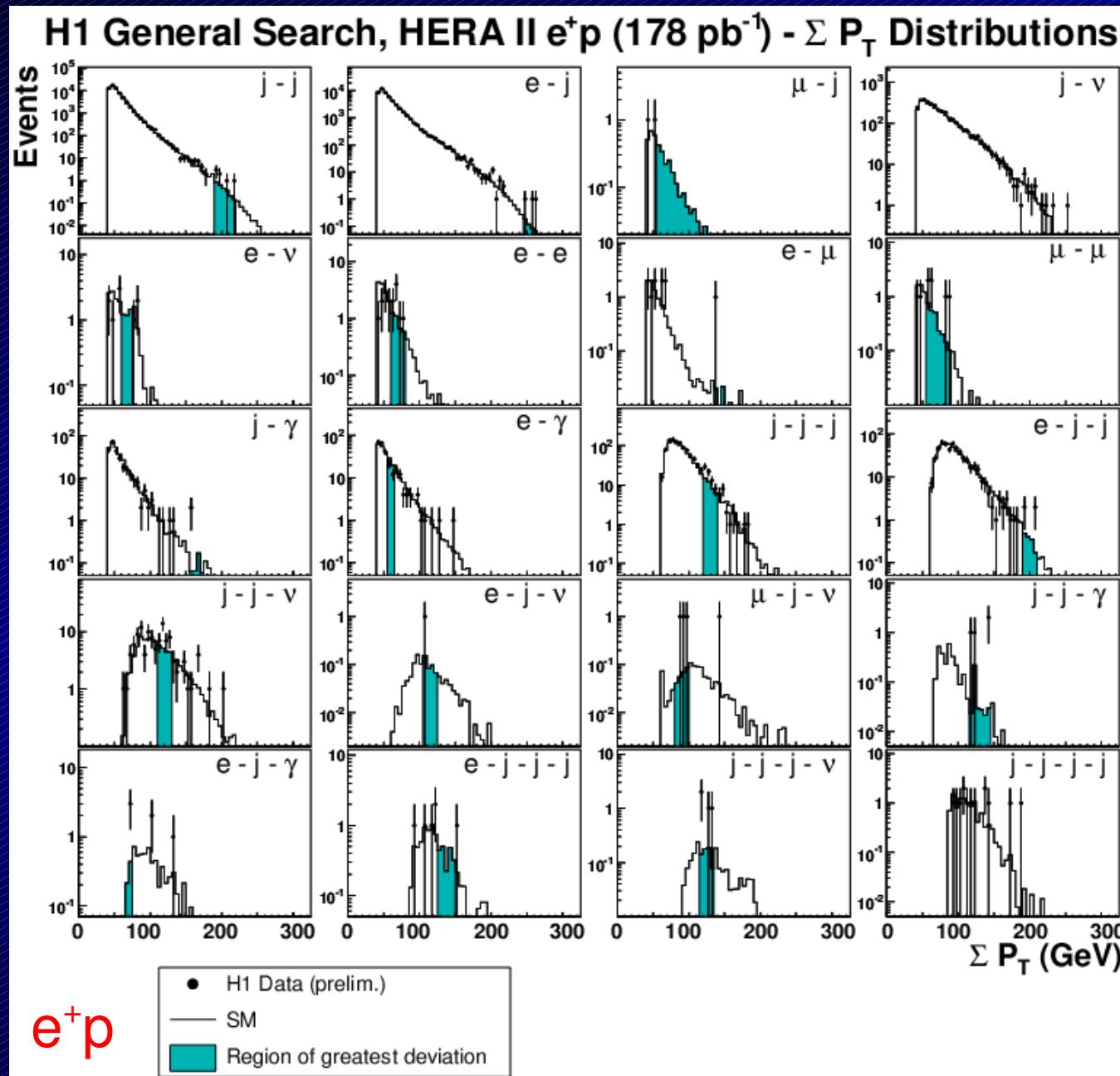


- Good agreement everywhere
- Includes classes w/ ≥ 1 data event or > 1 expected SM event
- Error bars include theory uncertainty and experimental systematics



H1 Σp_T Comparison

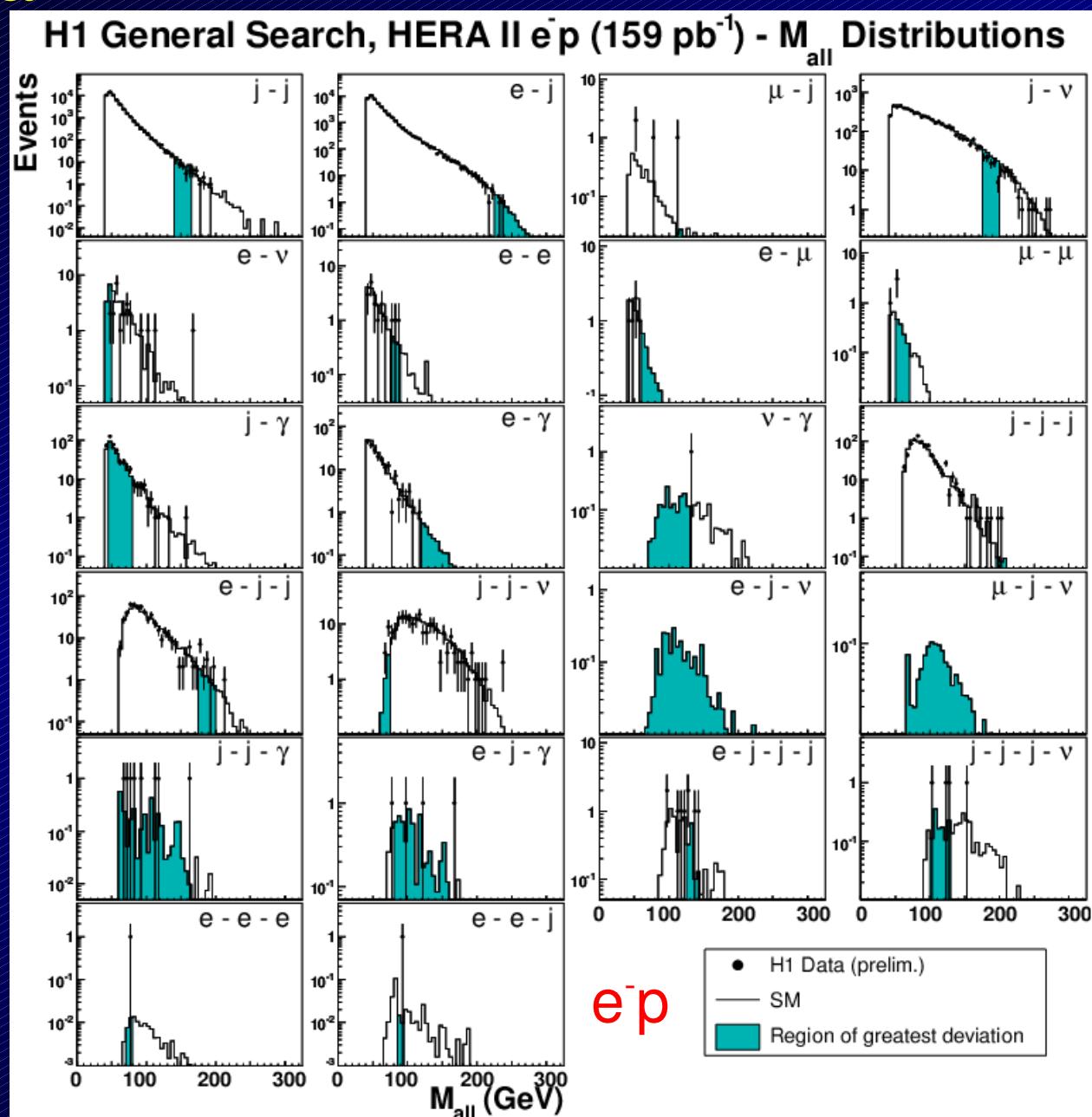
- Find regions of greatest deviation between data and SM expectation
- All groups of neighboring 5 GeV bins are tested
- Evaluate probability (p) for \pm fluctuations of SM expectations at least as large as data observation
 - Account for statistical errors (Poisson) and systematic uncertainties (Gaussian)
 - Take region with smallest p -value





H1 M_{all} Comparison

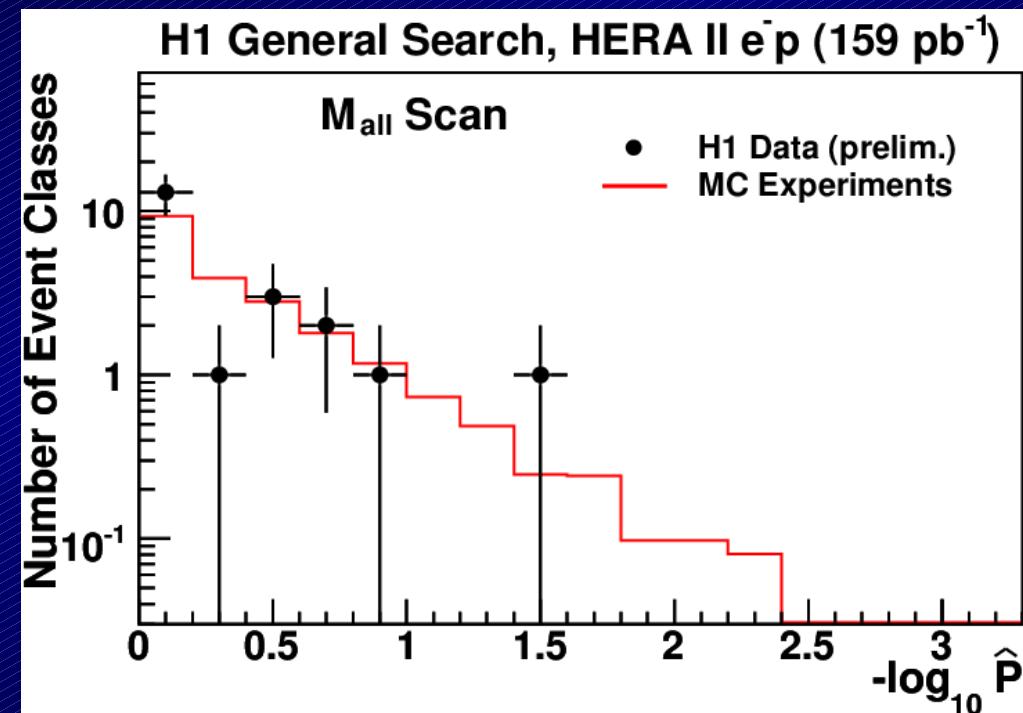
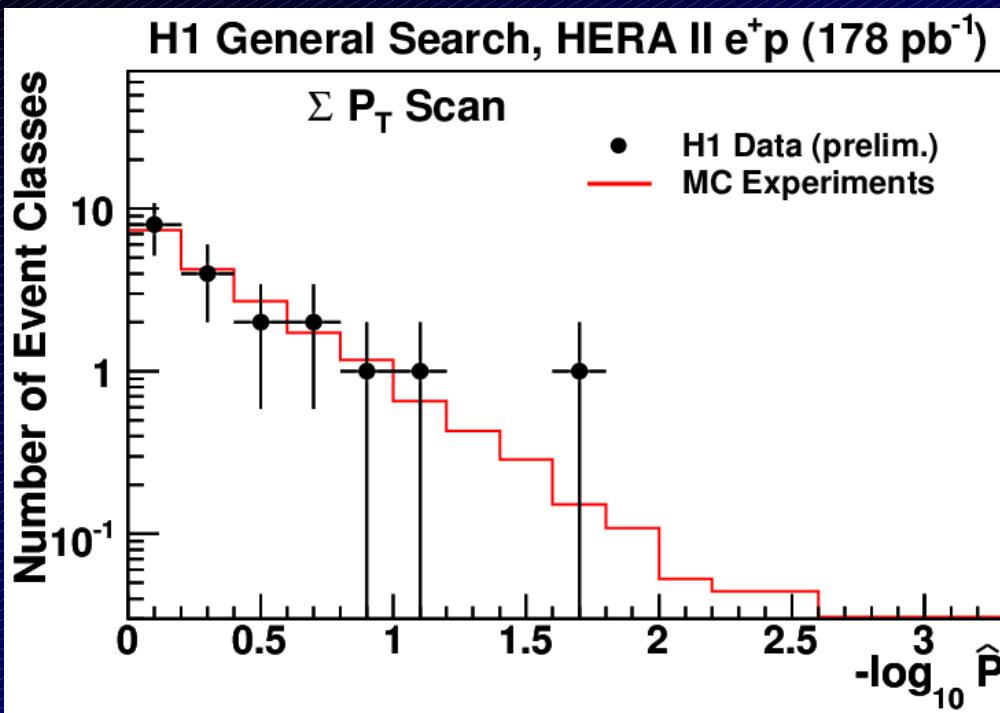
- Same procedure for M_{all} in e^-p collisions
- How significant are the deviations?
 - Use pseudo-data to answer this
 - Probability (\hat{P}) to observe region with $p < p_{\min}$ seen in data
 - Can compare \hat{P} for different event classes





H1 Significance Summary

- Combine \hat{P} from various event classes into one plot per variable
- 5 σ corresponds to $-\log_{10} \hat{P} = 5$ to 6



- No significant discrepancies between data and SM expectation
- The largest deviation is in the $\mu j \nu$ event class

Conclusions

- Model-independent global searches at CDF and H1
- The CDF search finds no indication of new physics in populations, kinematic distributions, invariant mass peaks, or high- Σp_T

<http://www-cdf.fnal.gov/physics/exotics/exotic.html>

Phys. Rev. D 78, 012002 (2008) CDF II results using 1 fb^{-1}

- The H1 search finds no indication of new physics in populations, Σp_T distributions, or invariant mass distributions

http://www-h1.desy.de/publications/H1preliminary.short_list.html#REX

Phys. Lett. B 602, 14 (2004) HERA I H1 results using 117 pb^{-1}

- Provide broad view of high- p_T data samples, and enhance understanding of detectors and standard model simulation
- Happily, they do not rule out new physics

Backup Slides →



Vista Correction Factors

- 43 correction factors, with values and errors obtained from global fit
- Only applicable within the Vista correction model

| CDF Run II Preliminary (2.0 fb^{-1}) | | | Value | Error | Error(%) |
|--|------------|---|-----------------------|----------------------|----------|
| Code | Category | Explanation | | | |
| 0001 | luminosity | CDF integrated luminosity | 1990 | 50 | 2.6 |
| 0002 | k-factor | cosmic_ph | 0.83 | 0.05 | 6.0 |
| 0003 | k-factor | cosmic_j | 0.192 | 0.006 | 3.1 |
| 0004 | k-factor | $1\gamma 1j$ photon+jet(s) | 0.92 | 0.04 | 4.4 |
| 0005 | k-factor | $1\gamma 2j$ | 1.26 | 0.05 | 4.0 |
| 0006 | k-factor | $1\gamma 3j$ | 1.61 | 0.08 | 5.0 |
| 0007 | k-factor | $1\gamma 4j+$ | 1.94 | 0.16 | 8.3 |
| 0008 | k-factor | $2\gamma 0j$ diphoton(+jets) | 1.6 | 0.08 | 5.0 |
| 0009 | k-factor | $2\gamma 1j$ | 2.99 | 0.17 | 5.7 |
| 0010 | k-factor | $2\gamma 2j+$ | 1.2 | 0.09 | 7.5 |
| 0011 | k-factor | $W0j$ W (+jets) | 1.38 | 0.03 | 2.2 |
| 0012 | k-factor | $W1j$ | 1.33 | 0.03 | 2.3 |
| 0013 | k-factor | $W2j$ | 1.99 | 0.05 | 2.5 |
| 0014 | k-factor | $W3j+$ | 2.11 | 0.09 | 4.3 |
| 0015 | k-factor | $Z0j$ Z (+jets) | 1.39 | 0.028 | 2.0 |
| 0016 | k-factor | $Z1j$ | 1.23 | 0.04 | 3.2 |
| 0017 | k-factor | $Z2j+$ | 1.02 | 0.04 | 3.9 |
| 0018 | k-factor | $2j \hat{p}_T < 150$ dijet | 1.003 | 0.027 | 2.7 |
| 0019 | k-factor | $2j 150 < \hat{p}_T$ | 1.34 | 0.03 | 2.2 |
| 0020 | k-factor | $3j \hat{p}_T < 150$ multijet | 0.941 | 0.025 | 2.7 |
| 0021 | k-factor | $3j 150 < \hat{p}_T$ | 1.48 | 0.04 | 2.7 |
| 0022 | k-factor | $4j \hat{p}_T < 150$ | 1.06 | 0.03 | 2.8 |
| 0023 | k-factor | $4j 150 < \hat{p}_T$ | 1.93 | 0.06 | 3.1 |
| 0024 | k-factor | 5j low | 1.33 | 0.05 | 3.8 |
| 0025 | k-factor | $1b2j 150 < \hat{p}_T$ | 2.22 | 0.11 | 5.0 |
| 0026 | k-factor | $1b3j 150 < \hat{p}_T$ | 2.98 | 0.15 | 5.0 |
| 0027 | misId | $p(e \rightarrow e)$ central | 0.978 | 0.006 | 0.6 |
| 0028 | misId | $p(e \rightarrow e)$ plug | 0.966 | 0.007 | 0.7 |
| 0029 | misId | $p(\mu \rightarrow \mu)$ CMUP+CMX | 0.888 | 0.007 | 0.8 |
| 0030 | misId | $p(\gamma \rightarrow \gamma)$ central | 0.949 | 0.018 | 1.9 |
| 0031 | misId | $p(\gamma \rightarrow \gamma)$ plug | 0.859 | 0.016 | 1.9 |
| 0032 | misId | $p(b \rightarrow b)$ central | 0.978 | 0.021 | 2.1 |
| 0033 | misId | $p(\gamma \rightarrow e)$ plug | 0.06 | 0.003 | 5.0 |
| 0034 | misId | $p(q \rightarrow e)$ central | 7.09×10^{-5} | 1.9×10^{-6} | 2.7 |
| 0035 | misId | $p(q \rightarrow e)$ plug | 0.000766 | 1.2×10^{-5} | 1.6 |
| 0036 | misId | $p(q \rightarrow \mu)$ | 1.14×10^{-5} | 6×10^{-7} | 5.2 |
| 0037 | misId | $p(b \rightarrow \mu)$ | 3.3×10^{-5} | 1.1×10^{-5} | 33.0 |
| 0038 | misId | $p(j \rightarrow b)$ $25 < p_T$ | 0.0183 | 0.0002 | 1.1 |
| 0039 | misId | $p(q \rightarrow \tau)$ | 0.0052 | 0.0001 | 1.9 |
| 0040 | misId | $p(q \rightarrow \gamma)$ central | 0.000266 | 1.4×10^{-5} | 5.3 |
| 0041 | misId | $p(q \rightarrow \gamma)$ plug | 0.00048 | 6×10^{-5} | 12.6 |
| 0042 | trigger | $p(e \rightarrow \text{trig})$ plug, $p_T > 25$ | 0.86 | 0.007 | 0.8 |
| 0043 | trigger | $p(\mu \rightarrow \text{trig})$ CMUP+CMX, $p_T > 25$ | 0.916 | 0.004 | 0.4 |



Vista Final State Populations

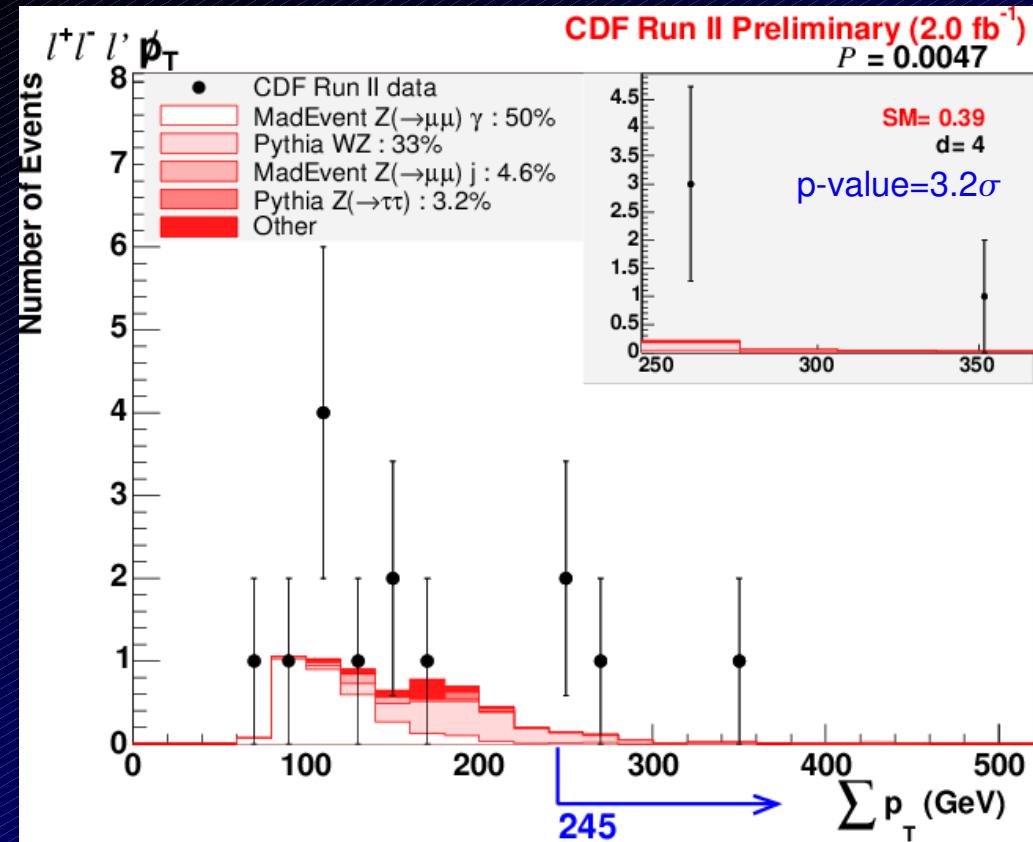
CDF Run II Preliminary (2.0 fb^{-1})
The calculation of σ accounts for the trials factor

| Final State | Data | Background | σ | Final State | Data | Background | σ | Final State | Data | Background | σ |
|---------------------------------|--------|---------------------|----------|----------------------------------|--------|---------------------|----------|----------------------------------|--------|---------------------|----------|
| $b\epsilon^\pm p$ | 690 | 817.7 ± 9.2 | -2.7 | $2j\bar{p}$ high- Σp_T | 87 | 80.9 ± 6.8 | 0 | $j\mu^\pm \mu^\mp \bar{p}$ | 32 | 32.2 ± 10.9 | 0 |
| $\gamma\tau^\pm$ | 1371 | 1217.6 ± 13.3 | +2.2 | $2j\bar{p}$ low- Σp_T | 114 | 79.5 ± 100.8 | 0 | $j\mu^\pm \mu^\mp \gamma$ | 14 | 11.5 ± 2.6 | 0 |
| $\mu^\pm \tau^\pm$ | 63 | 35.2 ± 2.8 | +1.7 | $2j\bar{p}\tau^\pm$ | 18 | 13.2 ± 2.2 | 0 | $j\mu^\pm \mu^\mp$ | 4852 | 4271.2 ± 185.4 | 0 |
| $b2j\bar{p}$ high- Σp_T | 255 | 327.2 ± 8.9 | -1.7 | $2j\gamma\bar{p}$ | 142 | 144.6 ± 5.7 | 0 | $j\mu^\pm$ | 77689 | 76987.5 ± 930.2 | 0 |
| $2j\tau^\pm$ low- Σp_T | 574 | 670.3 ± 8.6 | -1.5 | $2j\gamma$ | 908 | 980.3 ± 63.7 | 0 | $e^\pm 4j\bar{p}$ | 903 | 830.6 ± 13.2 | 0 |
| $3j\tau^\pm$ low- Σp_T | 148 | 199.8 ± 5.2 | -1.4 | $2j\mu^\pm \tau^\mp$ | 16 | 19.3 ± 2.2 | 0 | $e^\pm 4j\gamma$ | 25 | 29.2 ± 3.6 | 0 |
| $e^\pm p\tau^\pm$ | 36 | 17.2 ± 1.7 | +1.4 | $2j\mu^\pm \bar{p}$ | 17927 | 18340.6 ± 201.9 | 0 | $e^\pm 4j$ | 15750 | 16740.4 ± 390.5 | 0 |
| $2j\tau^\pm \tau^\mp$ | 33 | 62.1 ± 4.3 | -1.3 | $2j\mu^\pm \gamma\bar{p}$ | 31 | 27.7 ± 7.7 | 0 | $e^\pm 3j\tau^\mp$ | 15 | 21.1 ± 2.2 | 0 |
| $e^\pm j$ | 741710 | 764832 ± 6447.2 | -1.3 | $2j\mu^\pm \gamma$ | 57 | 58.2 ± 13 | 0 | $e^\pm 3j\bar{p}$ | 4054 | 4077.2 ± 63.6 | 0 |
| $j2\tau^\pm$ | 105 | 150.8 ± 6.3 | -1.2 | $2j\mu^\pm \mu^\mp \bar{p}$ | 11 | 7.8 ± 2.7 | 0 | $e^\pm 3j\gamma$ | 108 | 79.3 ± 5 | 0 |
| $e^\pm 2j$ | 256946 | 249148 ± 2201.5 | +1.2 | $2j\mu^\pm \mu^\mp$ | 956 | 924.9 ± 61.2 | 0 | $e^\pm 3j$ | 60725 | 60409.3 ± 723.3 | 0 |
| $2bj$ low- Σp_T | 279 | 352.5 ± 11.9 | -1.1 | $2j\mu^\pm$ | 22461 | 23111.4 ± 366.6 | 0 | $e^\pm 2\gamma$ | 41 | 34.2 ± 2.6 | 0 |
| $j\tau^\pm$ low- Σp_T | 1385 | 1525.8 ± 15 | -1.1 | $2e^\pm j$ | 14 | 13.8 ± 2.3 | 0 | $e^\pm 2j\tau^\pm$ | 37 | 47.2 ± 2.2 | 0 |
| $2b2j$ low- Σp_T | 108 | 153.5 ± 6.8 | -1 | $2e^\pm e^\mp$ | 20 | 17.5 ± 1.7 | 0 | $e^\pm 2j\tau^\mp$ | 109 | 95.9 ± 6.8 | 0 |
| $b\mu^\pm p$ | 528 | 613.5 ± 8.7 | -0.9 | $2e^\pm$ | 32 | 49.2 ± 3.4 | 0 | $e^\pm 2j\bar{p}$ | 25725 | 25403.1 ± 209.4 | 0 |
| $\mu^\pm \gamma\bar{p}$ | 523 | 611 ± 12.1 | -0.8 | $2b$ high- Σp_T | 666 | 689 ± 9.4 | 0 | $e^\pm 2j\gamma$ | 30 | 31.8 ± 4.8 | 0 |
| $2b\gamma$ | 108 | 70.5 ± 7.9 | +0.1 | $2b$ low- Σp_T | 323 | 313.2 ± 10.3 | 0 | $e^\pm 2j\mu^\mp$ | 398 | 342.8 ± 15.7 | 0 |
| $8j$ | 14 | 13.1 ± 4.4 | 0 | $2b3j$ low- Σp_T | 53 | 57.4 ± 6.5 | 0 | $e^\pm 2j\mu^\mp \bar{p}$ | 22 | 14.8 ± 1.9 | 0 |
| $7j$ | 103 | 97.8 ± 12.2 | 0 | $2b2j$ high- Σp_T | 718 | 803.3 ± 12.7 | 0 | $e^\pm 2j\mu^\mp$ | 23 | 15.8 ± 2 | 0 |
| $6j$ | 653 | 659.7 ± 37.3 | 0 | $2b2j\bar{p}$ high- Σp_T | 15 | 21.8 ± 2.8 | 0 | $e^\pm \tau^\pm$ | 437 | 387 ± 5.3 | 0 |
| $5j$ | 3157 | 3178.7 ± 67.1 | 0 | $2b2j\gamma$ | 32 | 39.7 ± 6.2 | 0 | $e^\pm \tau^\pm \bar{p}$ | 1333 | 1266 ± 12.3 | 0 |
| $4j$ high- Σp_T | 88546 | 89096.6 ± 935.2 | 0 | $2b2j\mu^\pm \bar{p}$ | 14 | 17.3 ± 1.9 | 0 | $e^\pm \bar{p}$ | 960826 | 956579 ± 3077.7 | 0 |
| $4j$ low- Σp_T | 14872 | 14809.6 ± 186.3 | 0 | $2b2j\mu^\pm$ | 22 | 21.8 ± 2 | 0 | $e^\pm \tau^\pm \bar{p}$ | 109 | 106.1 ± 2.7 | 0 |
| $4j2\gamma$ | 46 | 46.4 ± 3.9 | 0 | $2b2\mu^\pm \bar{p}$ | 11 | 14.4 ± 2.1 | 0 | $e^\pm \gamma$ | 3578 | 3589.9 ± 24.1 | 0 |
| $4j\tau^\pm$ high- Σp_T | 29 | 26.6 ± 1.7 | 0 | $2bj$ high- Σp_T | 891 | 967.3 ± 13.2 | 0 | $e^\pm 1j\mu^\pm \bar{p}$ | 31 | 29.9 ± 1.6 | 0 |
| $4j\tau^\pm$ low- Σp_T | 43 | 63.1 ± 3.3 | 0 | $2bj\bar{p}$ high- Σp_T | 25 | 31.3 ± 3.1 | 0 | $e^\pm 1\mu^\pm \bar{p}$ | 109 | 99.4 ± 2.4 | 0 |
| $4j\bar{p}$ high- Σp_T | 1064 | 1012 ± 62.9 | 0 | $2bj\gamma$ | 71 | 54.5 ± 7.1 | 0 | $e^\pm \mu^\pm$ | 45 | 28.5 ± 1.8 | 0 |
| $4j\gamma\tau^\pm$ | 19 | 10.8 ± 2 | 0 | $2bj\mu^\pm \bar{p}$ | 12 | 10.7 ± 1.9 | 0 | $e^\pm \mu^\pm$ | 350 | 313 ± 5.4 | 0 |
| $4j\gamma\bar{p}$ | 62 | 104.2 ± 22.4 | 0 | $2be^\pm 2j\bar{p}$ | 30 | 27.3 ± 2.2 | 0 | $e^\pm j\bar{p}$ | 13 | 16.1 ± 3.9 | 0 |
| $4j\gamma$ | 7962 | 8271.2 ± 245.1 | 0 | $2be^\pm 2j$ | 72 | 66.5 ± 2.9 | 0 | $e^\pm j\tau^\pm$ | 386 | 418 ± 18.9 | 0 |
| $4j\mu^\pm \bar{p}$ | 574 | 590.5 ± 13.6 | 0 | $2be^\pm \bar{p}$ | 22 | 19.1 ± 2.2 | 0 | $e^\pm j\tau^\pm \bar{p}$ | 160 | 162.8 ± 3.5 | 0 |
| $4j\mu^\pm \mu^\mp$ | 38 | 48.4 ± 6.2 | 0 | $2be^\pm j\bar{p}$ | 19 | 19.4 ± 2.2 | 0 | $e^\pm j\bar{p}\tau^\pm$ | 48 | 44.6 ± 3.3 | 0 |
| $4j\mu^\pm$ | 1363 | 1350.1 ± 37.7 | 0 | $2be^\pm j$ | 63 | 63 ± 3.4 | 0 | $e^\pm j\bar{p}\tau^\pm \bar{p}$ | 11 | 8.3 ± 1.5 | 0 |
| $3j$ high- Σp_T | 159926 | 159143 ± 1061.9 | 0 | $2be^\pm$ | 96 | 92.1 ± 4.1 | 0 | $e^\pm j\bar{p}\tau^\pm \bar{p}$ | 121431 | 121023 ± 747.6 | 0 |
| $3j$ low- Σp_T | 62681 | 64213.1 ± 496 | 0 | $\tau^\pm \tau^\mp$ | 856 | 872.5 ± 19 | 0 | $e^\pm j\bar{p}$ | 159 | 192.6 ± 10.9 | 0 |
| $3j2\gamma$ | 151 | 177.5 ± 7.1 | 0 | $\gamma\bar{p}$ | 3793 | 3770.7 ± 127.3 | 0 | $e^\pm j\gamma\bar{p}$ | 1389 | 1368.9 ± 38.9 | 0 |
| $3j\tau^\pm$ high- Σp_T | 68 | 76.9 ± 3 | 0 | $\mu^\pm \tau^\mp$ | 381 | 440.9 ± 7.3 | 0 | $e^\pm j\gamma$ | 42 | 33 ± 2.9 | 0 |
| $3j\bar{p}$ high- Σp_T | 1706 | 1899.4 ± 77.6 | 0 | $\mu^\pm \bar{p}\tau^\mp$ | 60 | 75.7 ± 3.4 | 0 | $e^\pm j\mu^\pm \bar{p}$ | 16 | 9.2 ± 1.9 | 0 |
| $3j\bar{p}$ low- Σp_T | 42 | 36.2 ± 5.7 | 0 | $\mu^\pm \bar{p}\tau^\pm$ | 15 | 12 ± 2 | 0 | $e^\pm j\mu^\pm \bar{p}$ | 62 | 63.8 ± 3.2 | 0 |
| $3j\gamma\tau^\pm$ | 39 | 37.8 ± 3.6 | 0 | $\mu^\pm \bar{p}$ | 734290 | 734296 ± 4897.8 | 0 | $e^\pm j\mu^\pm \bar{p}$ | 13 | 8.2 ± 2 | 0 |
| $3j\gamma\bar{p}$ | 204 | 249.8 ± 24.4 | 0 | $\mu^\pm \gamma$ | 475 | 469.8 ± 12.5 | 0 | $e^\pm j\mu^\pm$ | 148 | 159.1 ± 7 | 0 |
| $3j\gamma$ | 24639 | 24899.4 ± 372.4 | 0 | $\mu^\pm \mu^\mp$ | 169 | 198.5 ± 8.2 | 0 | $e^\pm e^\mp 4j$ | 717 | 743.6 ± 24.4 | 0 |
| $3j\mu^\pm \bar{p}$ | 2884 | 2971.5 ± 52.1 | 0 | $\mu^\pm \mu^\mp \bar{p}$ | 83 | 60 ± 3.1 | 0 | $e^\pm e^\mp 3j$ | 32 | 41.4 ± 5.6 | 0 |
| $3j\mu^\pm \gamma\bar{p}$ | 10 | 3.6 ± 1.9 | 0 | $\mu^\pm \mu^\mp \gamma$ | 526 | 476 ± 9.3 | 0 | $e^\pm e^\mp 2j\bar{p}$ | 10 | 11.4 ± 2.9 | 0 |
| $3j\mu^\pm \gamma$ | 15 | 7.9 ± 2.9 | 0 | $\mu^\pm \mu^\mp \tau^\mp$ | 4432 | 4431.7 ± 45.2 | 0 | $e^\pm e^\mp 2j\gamma$ | 3638 | 3566.8 ± 72 | 0 |
| $3j\mu^\pm \mu^\mp$ | 175 | 177.8 ± 16.2 | 0 | $j2\gamma\bar{p}$ | 36 | 30.4 ± 4.2 | 0 | $e^\pm e^\mp 2j$ | 18 | 16.1 ± 1.7 | 0 |
| $3j\mu^\pm$ | 5032 | 4989.5 ± 108.9 | 0 | $j2\gamma$ | 1822 | 1813.2 ± 27.4 | 0 | $e^\pm e^\mp \tau^\pm$ | 822 | 831.8 ± 13.6 | 0 |
| $3b2j$ | 23 | 28.9 ± 4.7 | 0 | $j\tau^\pm$ high- Σp_T | 52 | 56.2 ± 2.5 | 0 | $e^\pm e^\mp \bar{p}$ | 191 | 221.9 ± 5.1 | 0 |
| $3bj$ | 82 | 82.6 ± 5.7 | 0 | $j\tau^\pm \tau^\mp$ | 203 | 252.2 ± 8.7 | 0 | $e^\pm e^\mp \gamma$ | 155 | 170.8 ± 12.4 | 0 |
| $3b$ | 67 | 85.6 ± 7.7 | 0 | $j\bar{p}$ high- Σp_T | 526 | 476 ± 9.3 | 0 | $e^\pm e^\mp j\bar{p}$ | 48 | 45 ± 3.9 | 0 |
| $2\tau^\pm$ | 498 | 512.7 ± 14.2 | 0 | $j\tau^\pm \tau^\mp$ | 1882 | 1791.9 ± 72.3 | 0 | $e^\pm e^\mp j\gamma$ | 17903 | 18258.2 ± 204.4 | 0 |
| $2\gamma\bar{p}$ | 128 | 107.2 ± 6.9 | 0 | $j\bar{p}$ | 103319 | 102124 ± 570.6 | 0 | $e^\pm e^\mp \tau^\pm$ | 98901 | 99086.9 ± 147.8 | 0 |
| 2γ | 5548 | 5562.8 ± 40.5 | 0 | $j\gamma$ | 71 | 98 ± 3.9 | 0 | $b6j$ | 51 | 42.3 ± 3.8 | 0 |
| $2j$ high- Σp_T | 190773 | 190842 ± 781.2 | 0 | $j\mu^\pm \tau^\mp$ | 15 | 12 ± 2 | 0 | $b5j$ | 237 | 192.5 ± 7.1 | 0 |
| $2j$ low- Σp_T | 165984 | 162530 ± 1581 | 0 | $j\mu^\pm \tau^\pm$ | 26 | 30.8 ± 2.6 | 0 | $b4j$ high- Σp_T | 26 | 23.4 ± 2.6 | 0 |
| $2j2\tau^\pm$ | 22 | 40.6 ± 3.2 | 0 | $j\mu^\pm \bar{p}\tau^\mp$ | 109081 | 108323 ± 707.7 | 0 | $b4j$ low- Σp_T | 836 | 821.7 ± 15.9 | 0 |
| $2j2\gamma\bar{p}$ | 11 | 8 ± 2.4 | 0 | $j\mu^\pm \bar{p}$ | 171 | 171.1 ± 31 | 0 | $b3j$ high- Σp_T | 12081 | 12071 ± 84.1 | 0 |
| $2j2\gamma$ | 580 | 581 ± 13.7 | 0 | $j\mu^\pm \gamma$ | 152 | 190 ± 39.3 | 0 | $b3j$ low- Σp_T | 2974 | 2873 ± 31 | 0 |

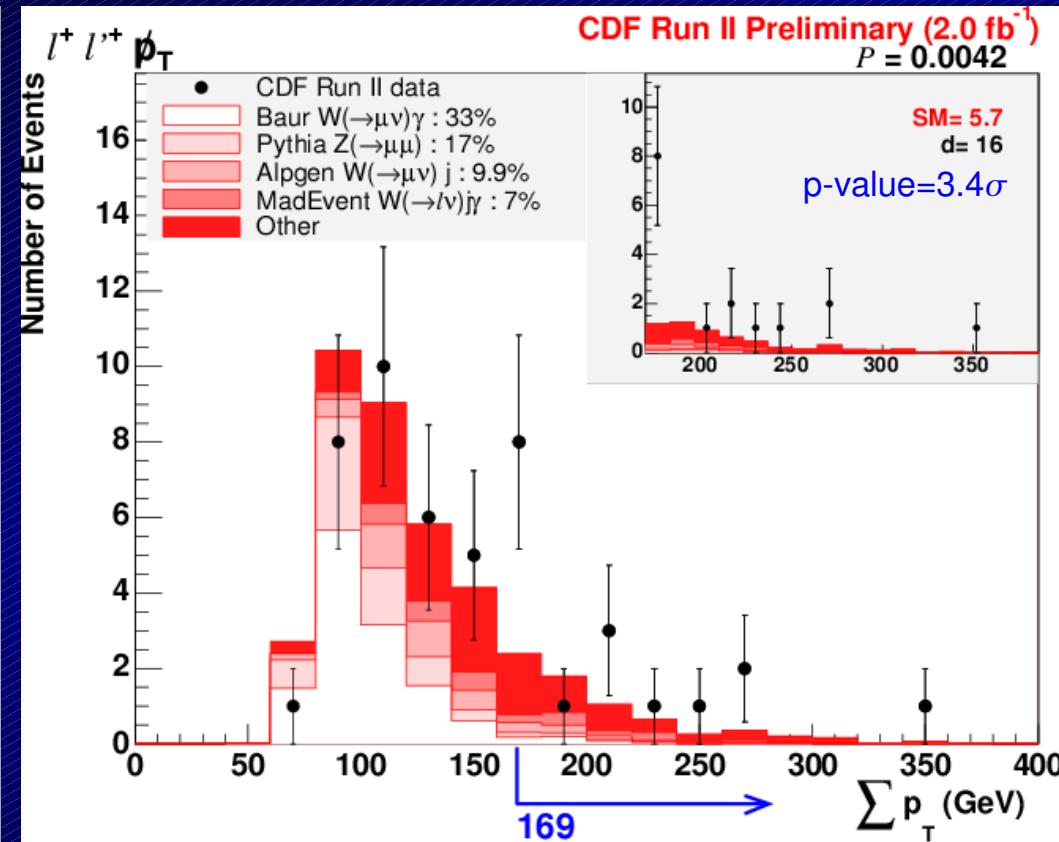
More Sleuth Results

#4

#3



- Final state: $\ell^+ \ell^- \ell' \not{p}_T$
 $\ell = e$ or μ
 $\ell' = e$ or μ , but different from ℓ
- Significance of region:
 $P = 0.0047$ (2.6σ) before trials factor,
50% probable after trials factor

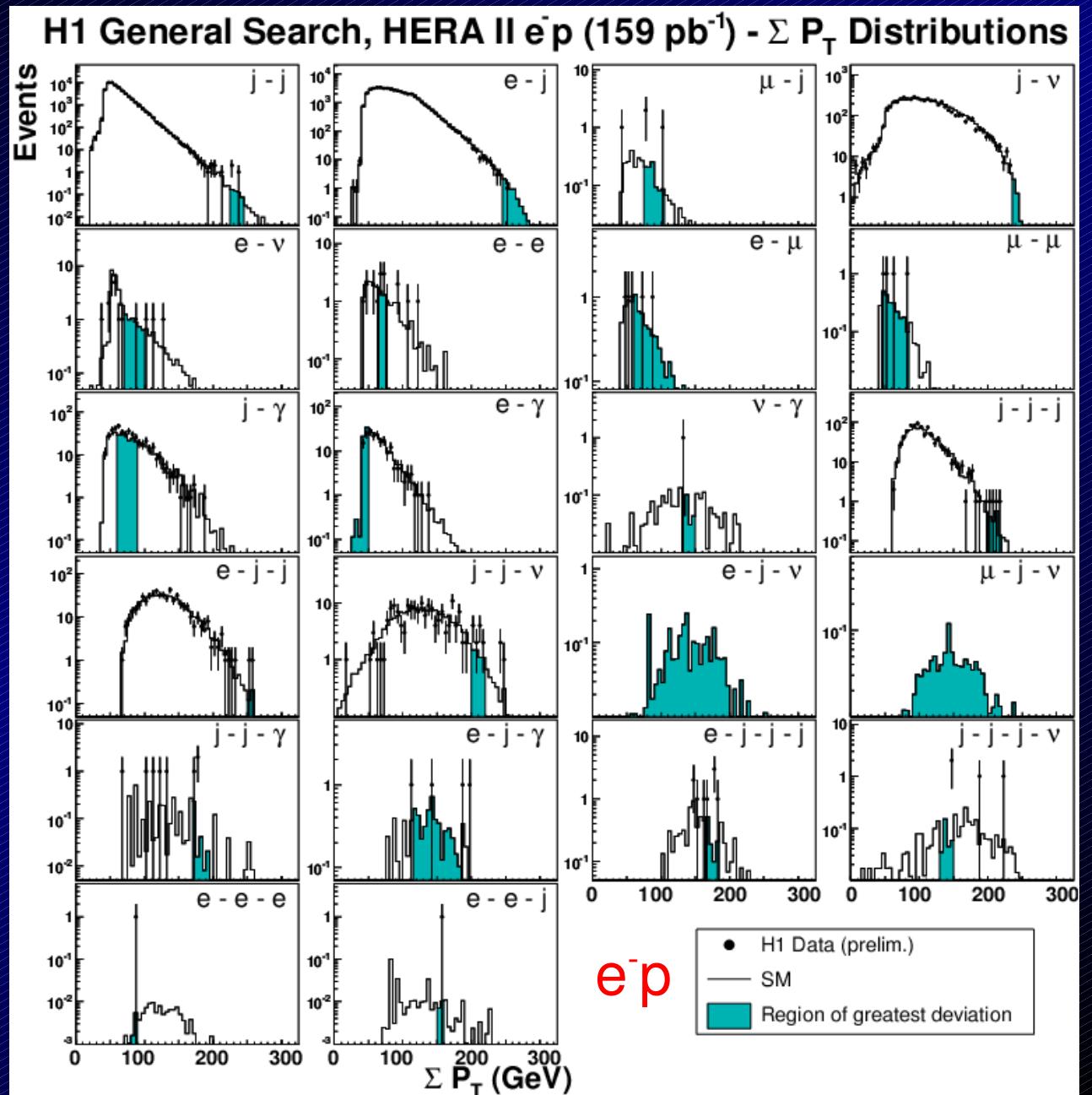


- Final state: $e^+ \mu^+ \not{p}_T$
- Significance of region:
 $P = 0.0042$ (2.6σ) before trials factor,
46% probable after trials factor



More H1 Σp_T Comparison

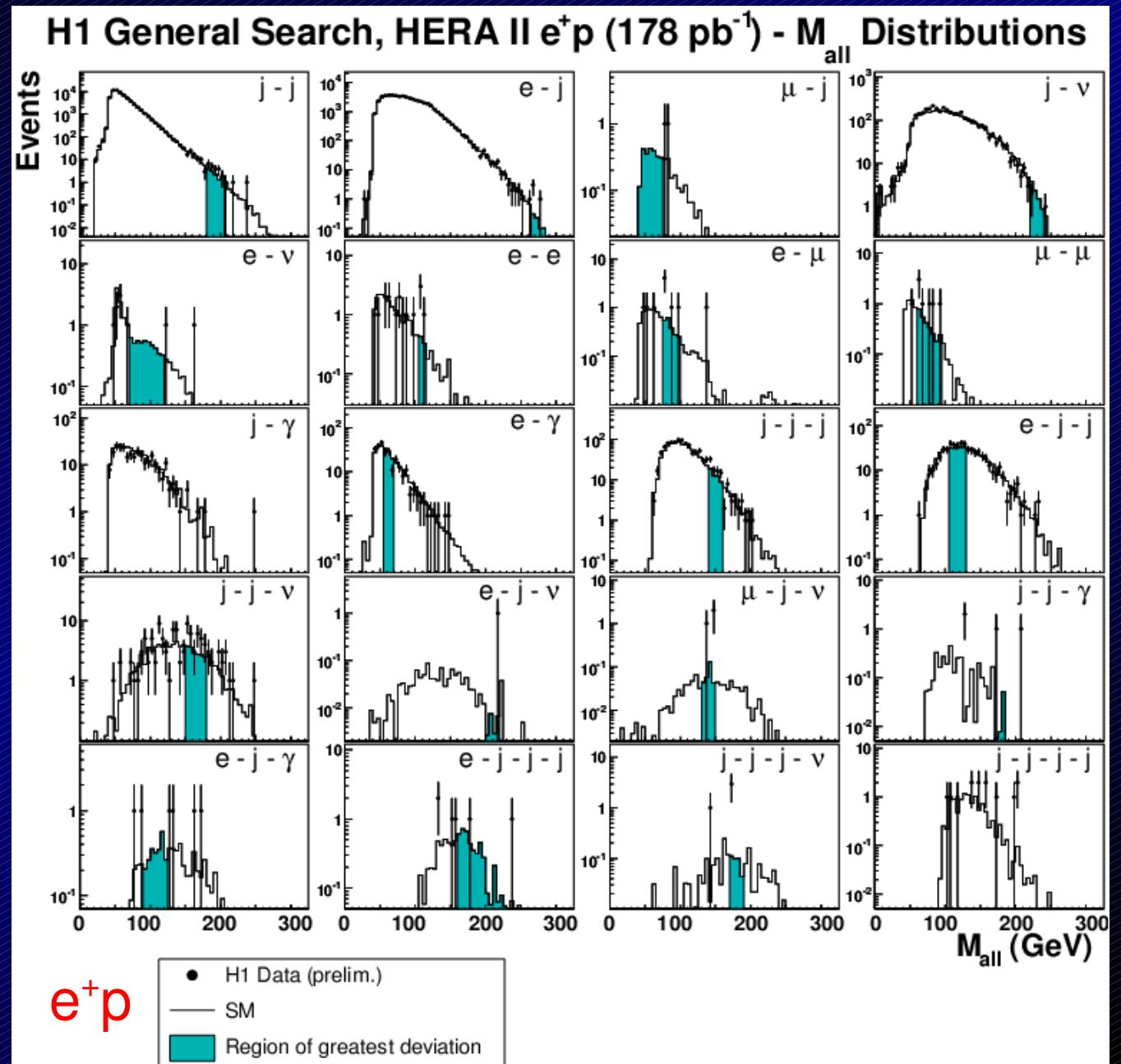
- These are for e^-p data





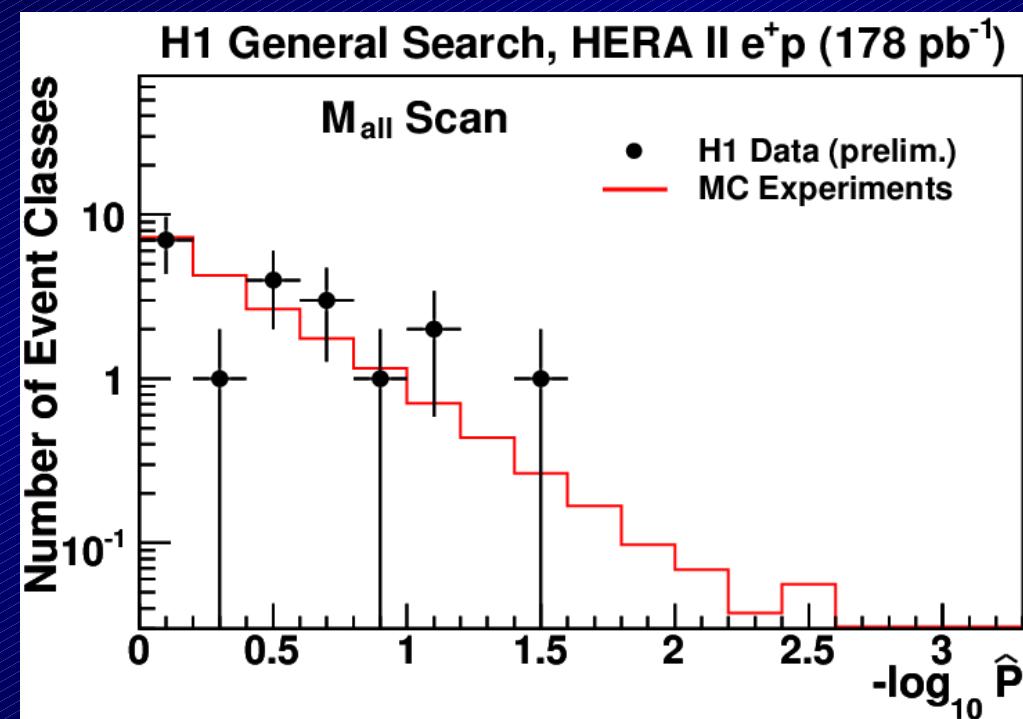
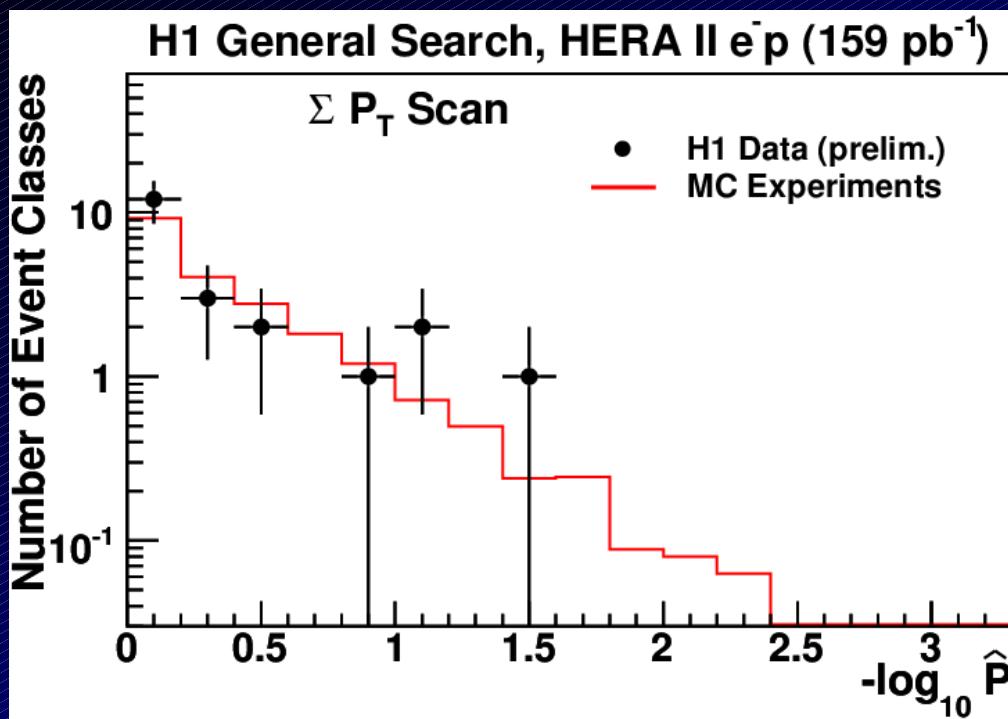
More H1 M_{all} Comparison

- These are for e^+p data





More H1 Significance Plots



- No significant discrepancies between data and SM expectation